The age of discovery with JWST: excavating the first massive BHs & galaxies

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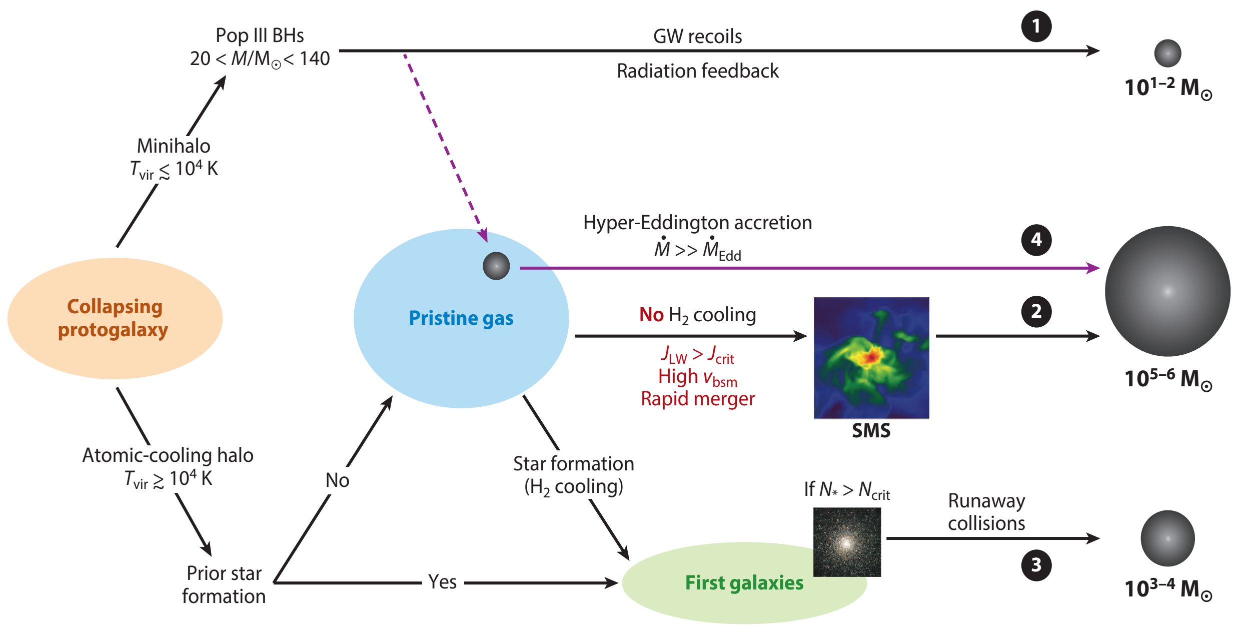
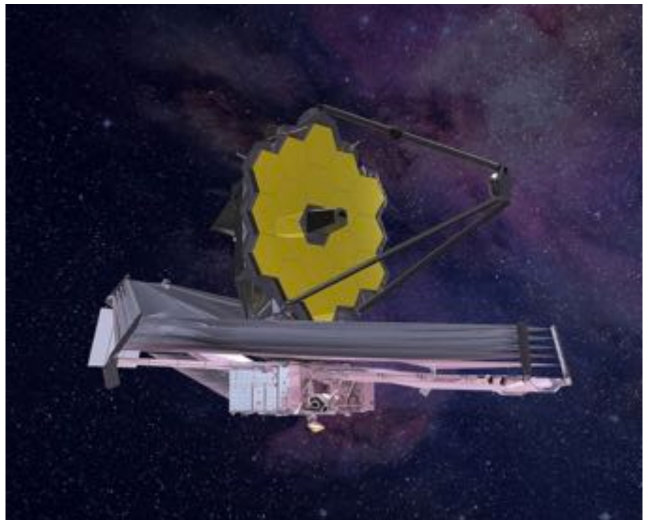
15th September 2022 @Tsinghua, DoA

Talk's outline

1. Introduction
2. Rapid Growth of BHs
3. Excavating the First Massive BHs



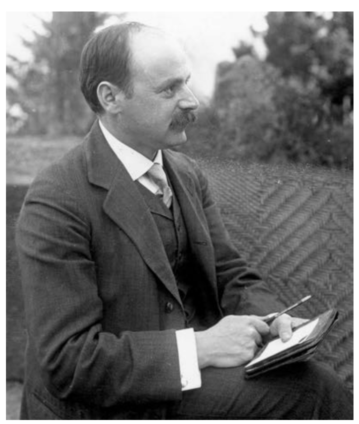


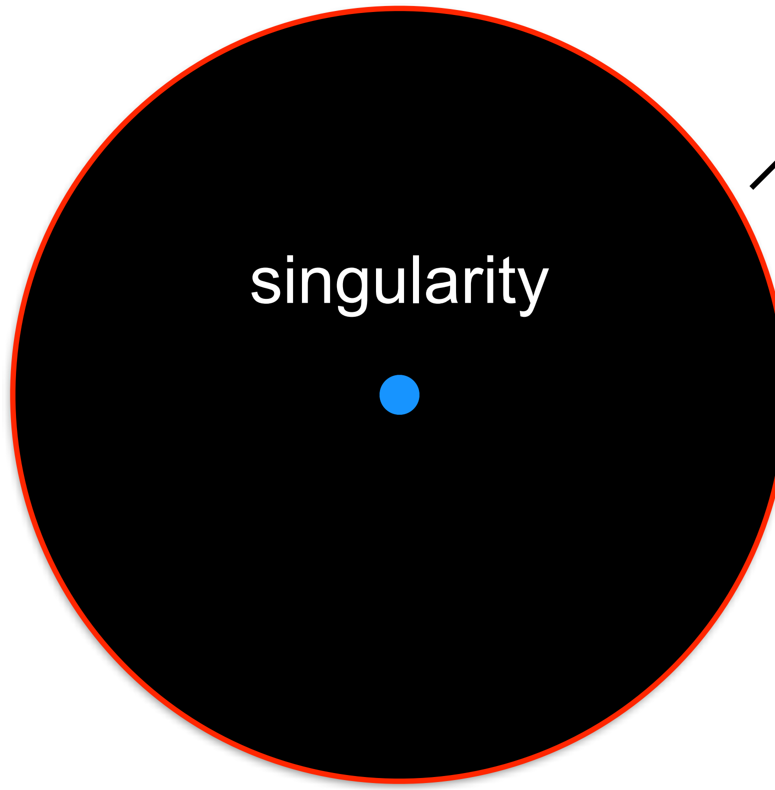
1. Introduction

Black Holes (BHs)

Three quantities to characterize the object

$$M, Q, J$$





<u>Event horizon</u>

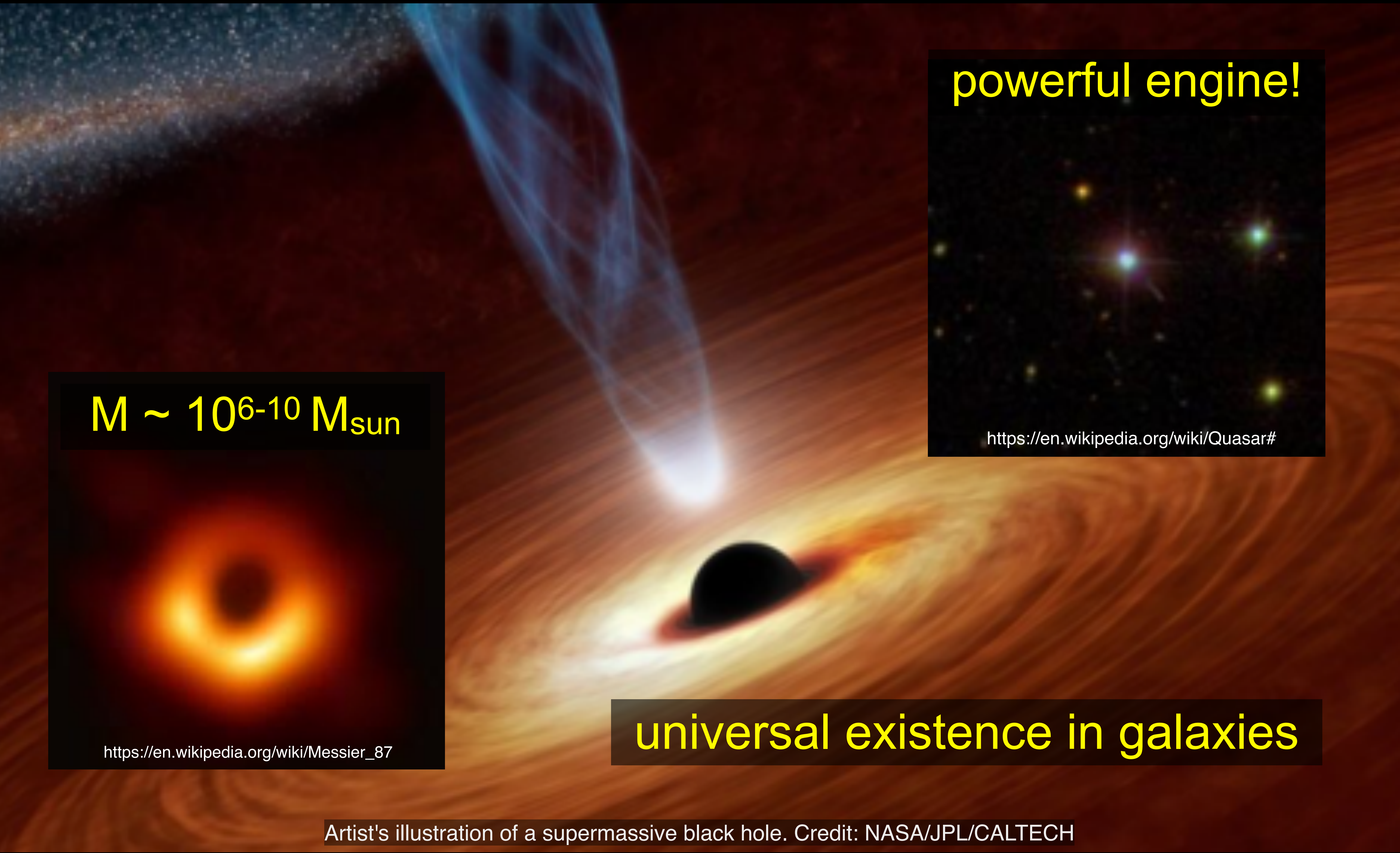
$$R_{\rm Sch} = \frac{2GM}{c^2}$$

for a non-rotating/ non-charged BH

(c.f. ~3km for $M_\odot$)

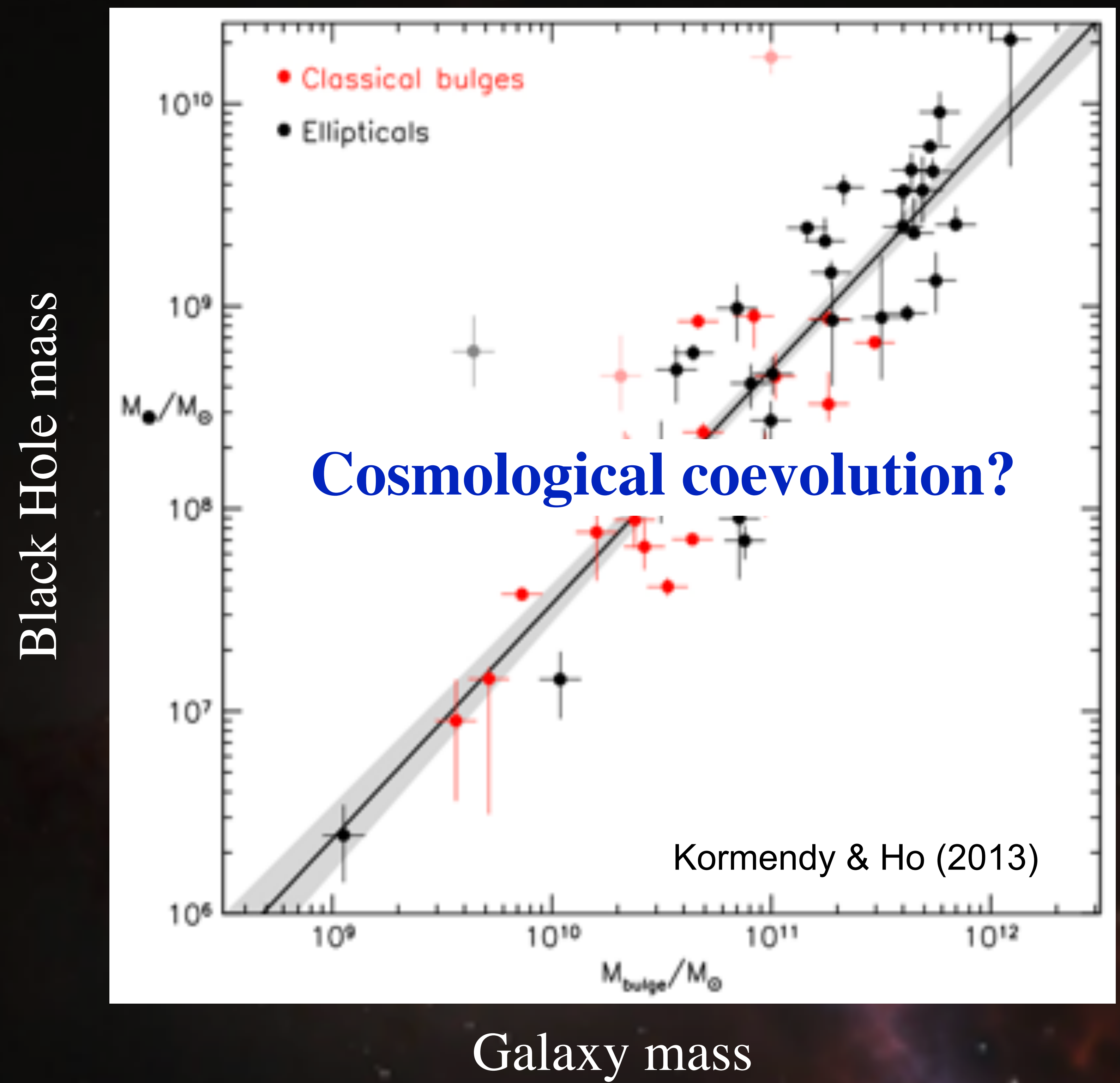
The theory of general relativity predicts that a sufficiently compact mass can deform spacetime to form ***<u>a black hole, where gravity is so strong that nothing (even lights!) can escape from it.</u>***

Supermassive black holes (SMBH)



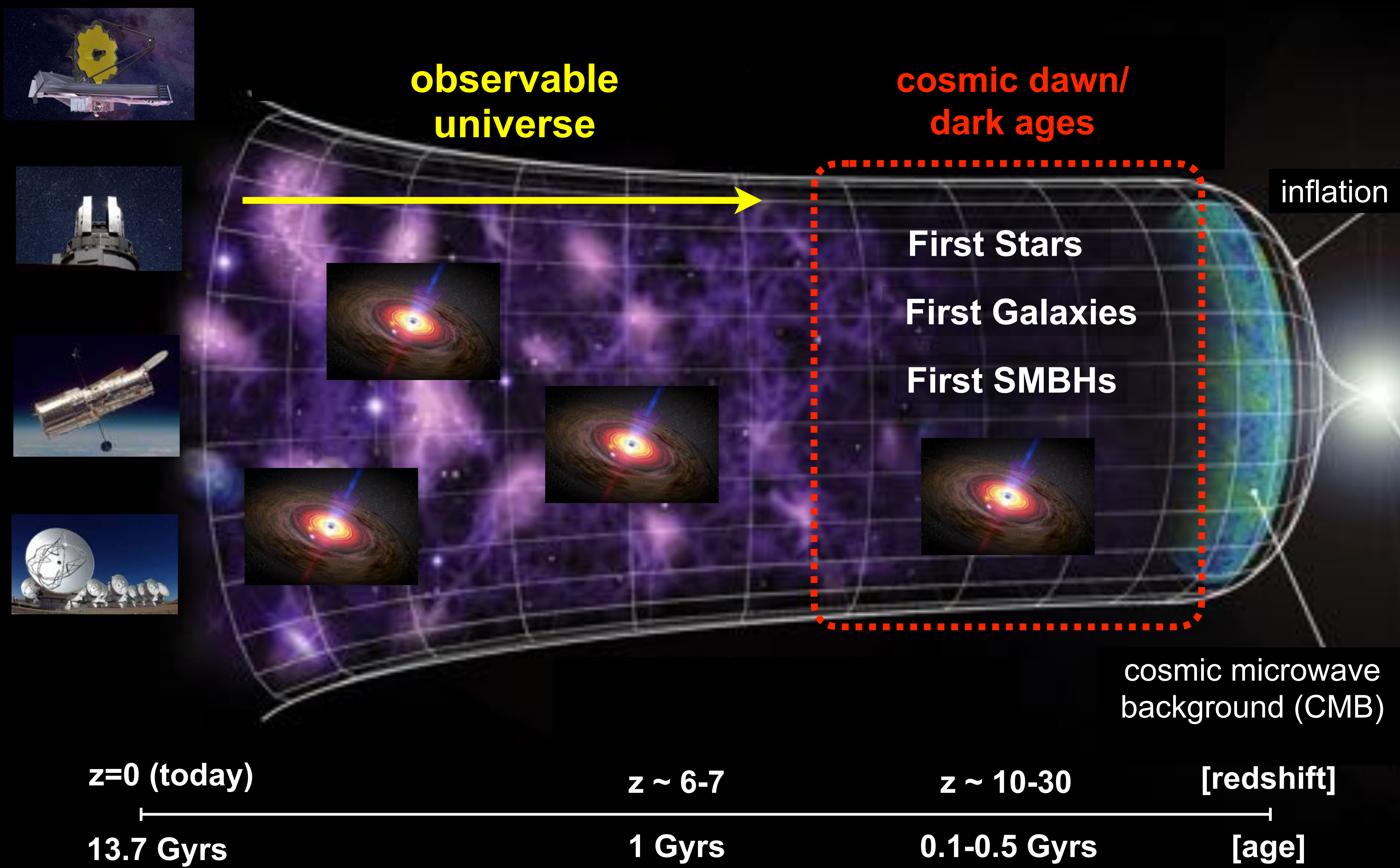
Artist's illustration of a supermassive black hole. Credit: NASA/JPL/CALTECH

Early BH-galaxy coevolution

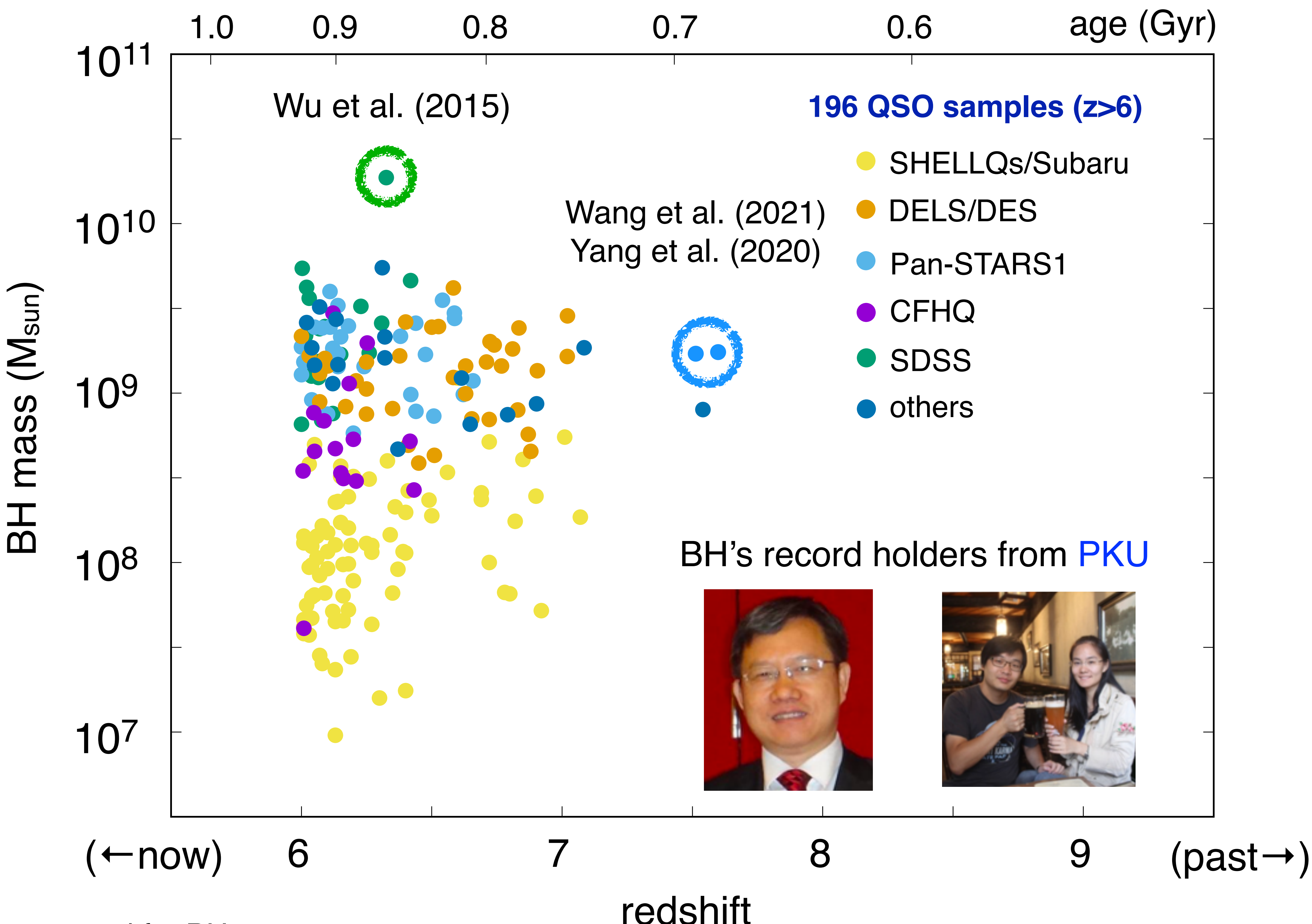


artist's illustration [ESA/Hubble, L. Calçada (ESO)]

History of the universe



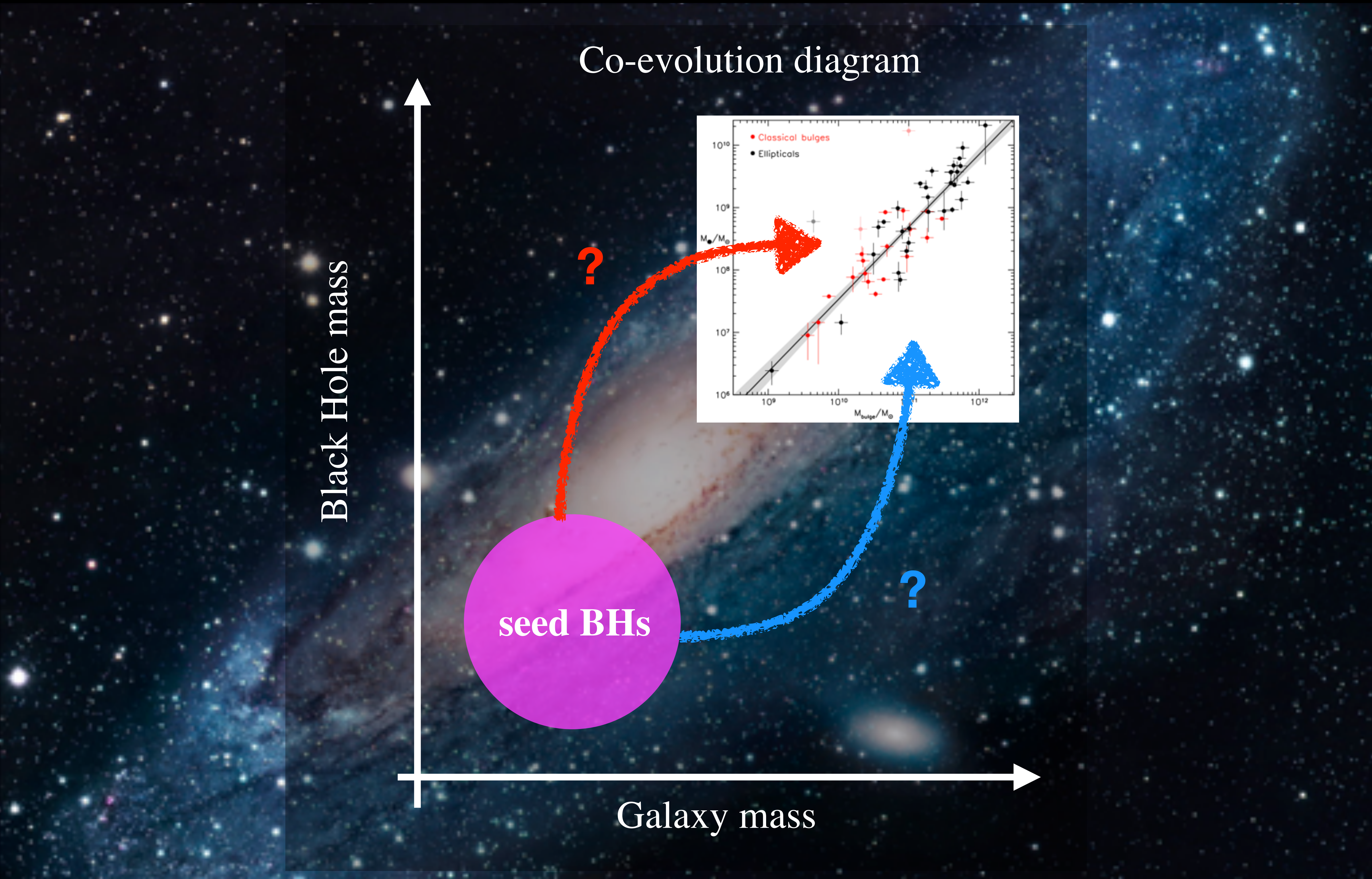
High-z SMBH population



*λ_{Edd}=1 is assumed for BHs if not mass measurements

KI, Visbal & Haiman (2020)

Early BH-galaxy coevolution

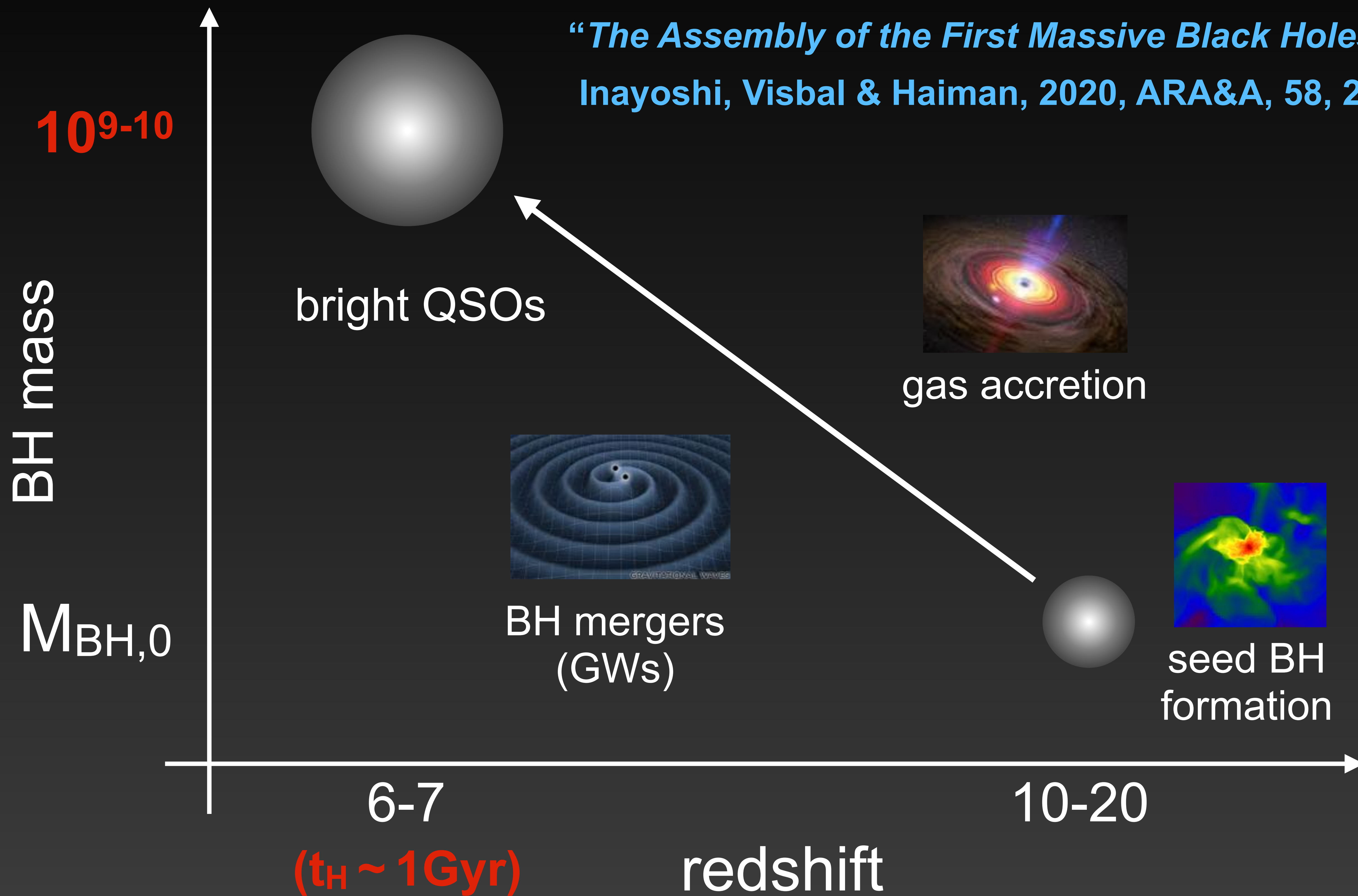


2. Rapid Growth of BHs

Rapid SMBH assembly

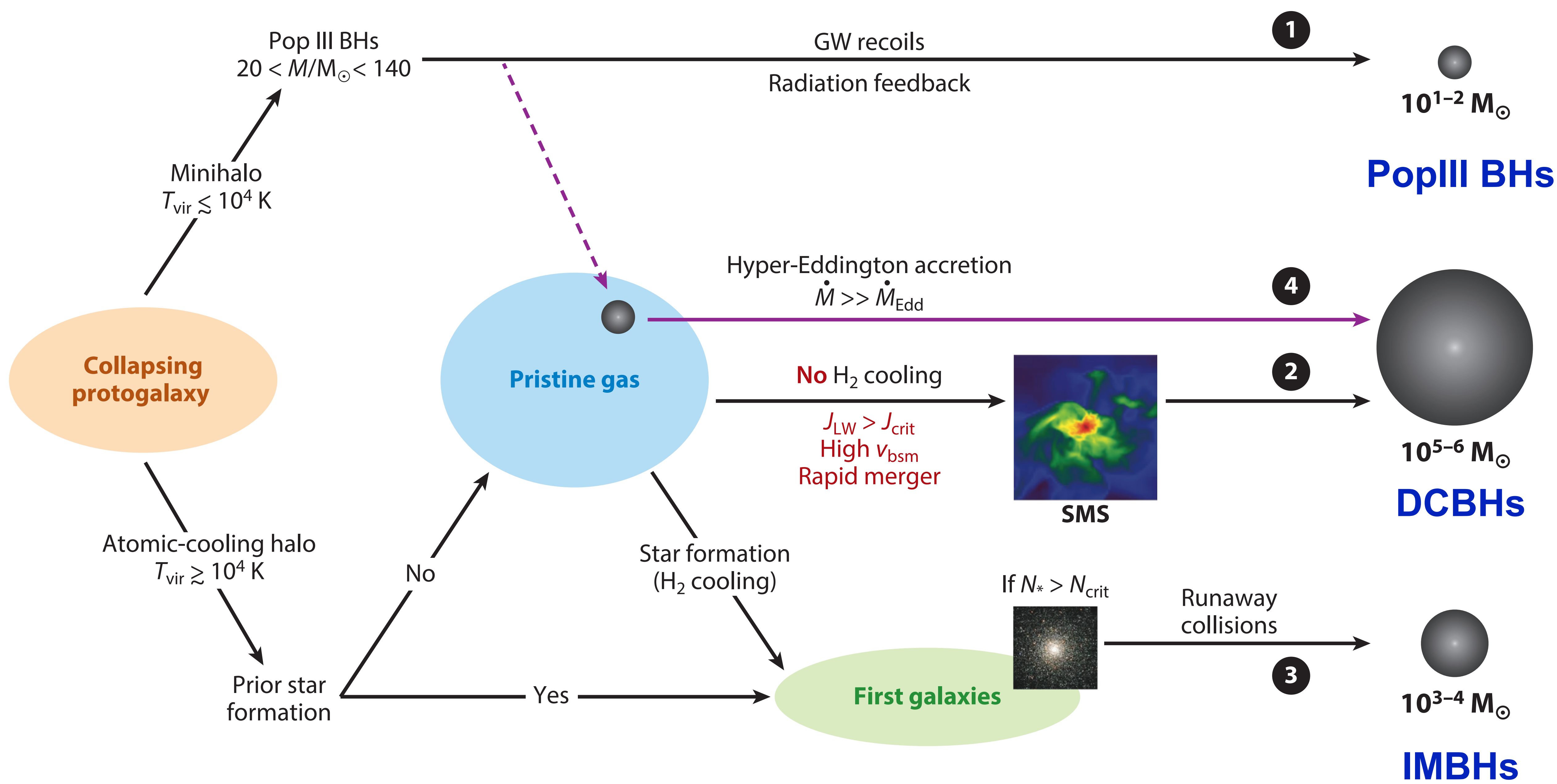
"The Assembly of the First Massive Black Holes"

Inayoshi, Visbal & Haiman, 2020, ARA&A, 58, 27



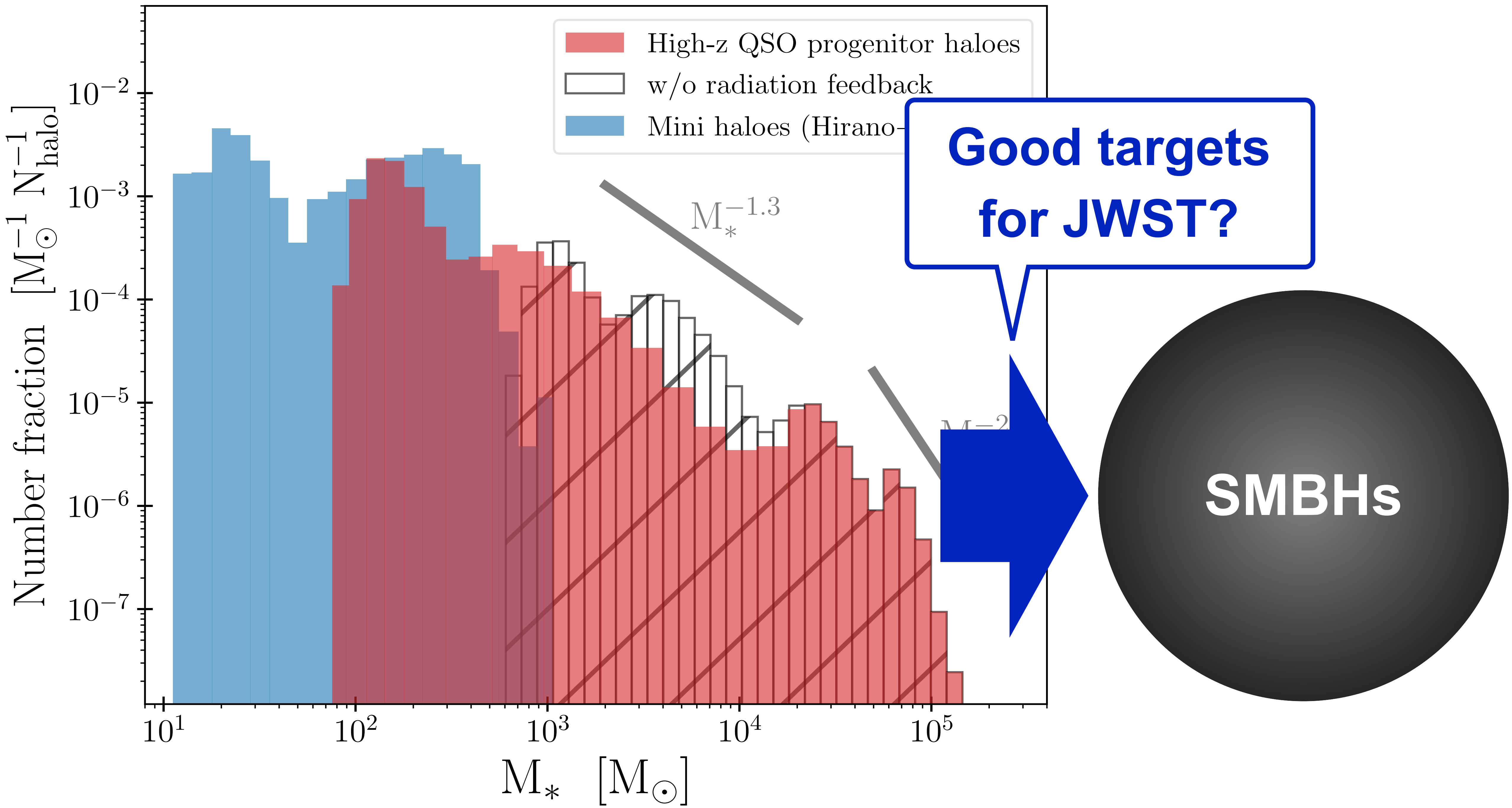
Formation channels of early BHs

Various masses of seed BHs depending on SF environments



KI, Visbal & Haiman (2020) ARA&A

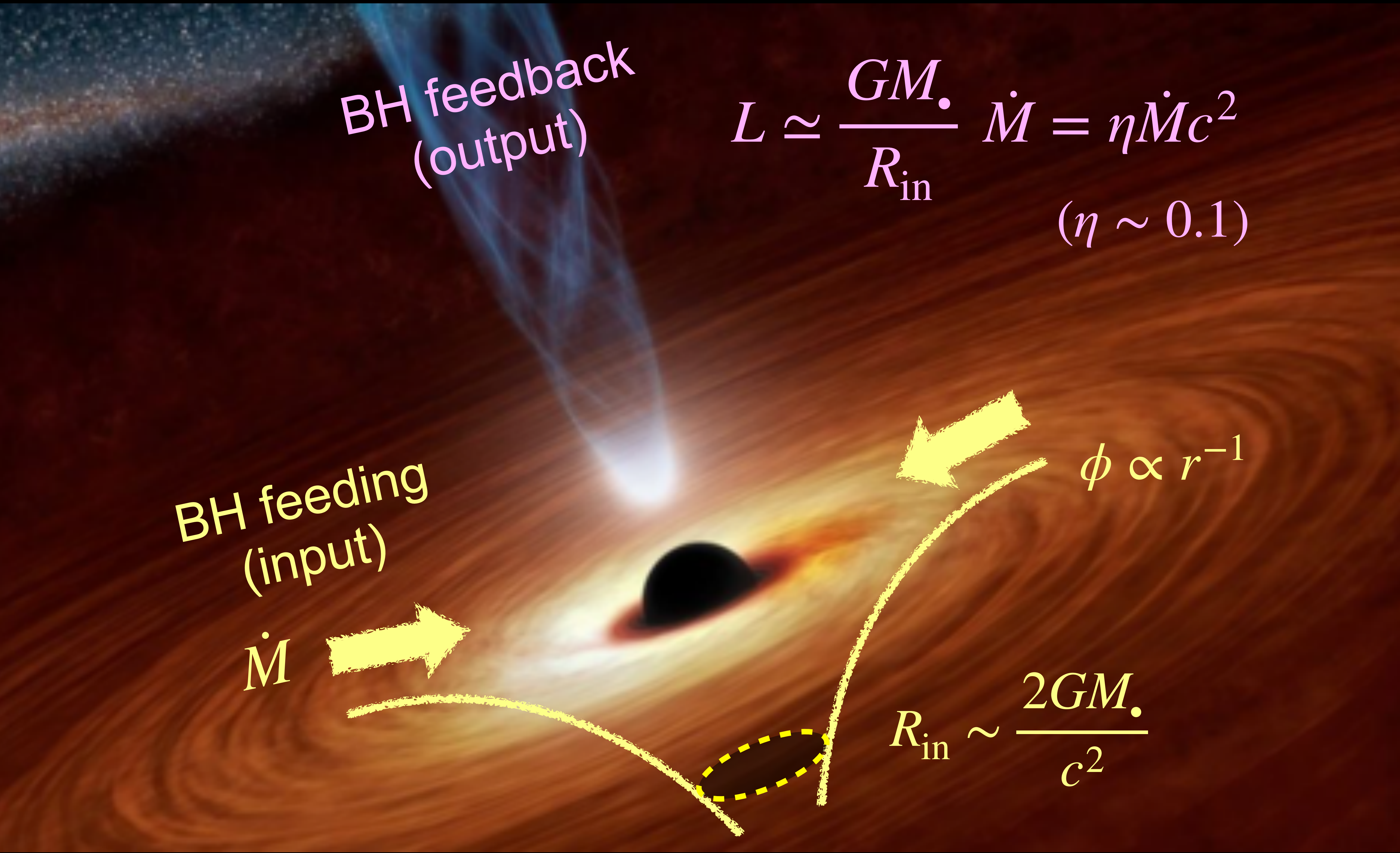
BH mass function in QSO host galaxies



RHD simulations + semi-analytical model for BH seeding

(Li et al. 2021; Toyouchi et al. 2022; see also Sassano et al. 2021)

The most efficient cosmic engine

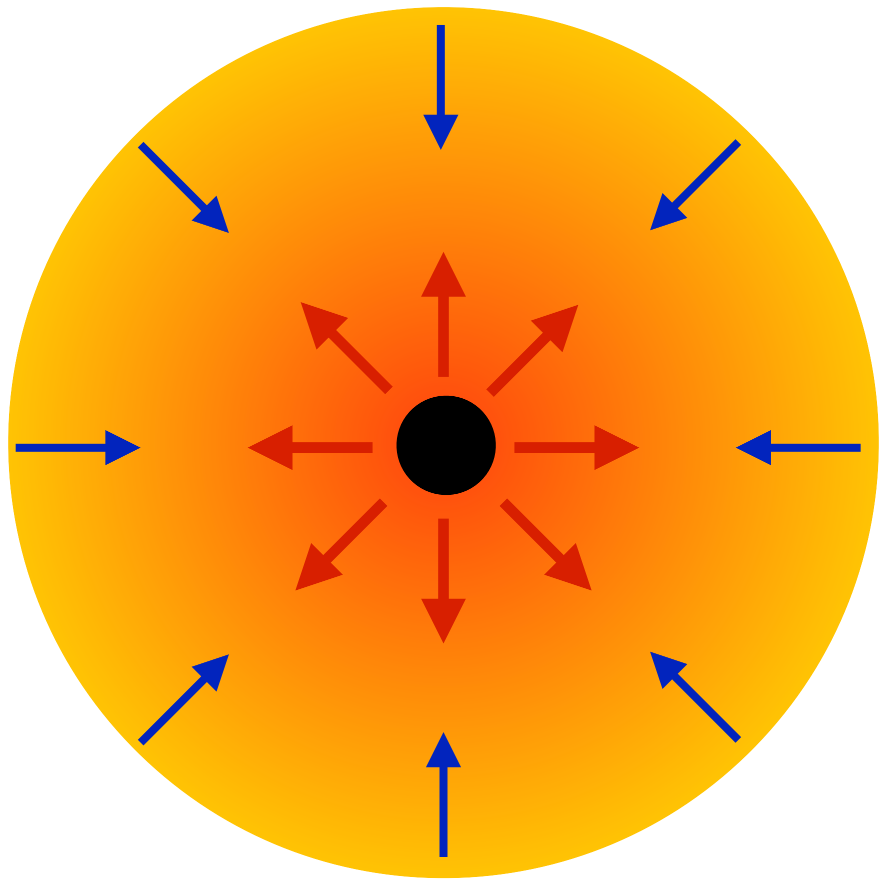


Eddington limit

- suppose a spherically symmetric system

BH gravity

$$g_{\rm grav} = \frac{GM_\bullet}{r^2}$$



radiation force

$$g_{\rm rad} = \frac{\kappa_{\rm e}}{c}\frac{L}{4\pi r^2}$$

we would naively impose $g_{\rm grav} \gtrsim g_{\rm rad}$ **"Eddington luminosity"**

$$L \lesssim \frac{4\pi c G M_\bullet}{\kappa_{\rm e}} \equiv L_{\rm Edd} \simeq 1.3 \times 10^{46}\ {\rm erg\ s^{-1}} \left(\frac{M_\bullet}{10^8\ M_\odot}\right)$$

Eddington limit

- Eddington limited accretion

$$\dot{M} = \frac{L}{\eta c^2} \lesssim \frac{L_{\rm Edd}}{\eta c^2} \equiv \dot{M}_{\rm Edd} \simeq 2.3\ M_\odot\ {\rm yr}^{-1} \left(\frac{M_\bullet}{10^8\ M_\odot} \right)$$

$\dot{M} \propto M$ (exponential growth)

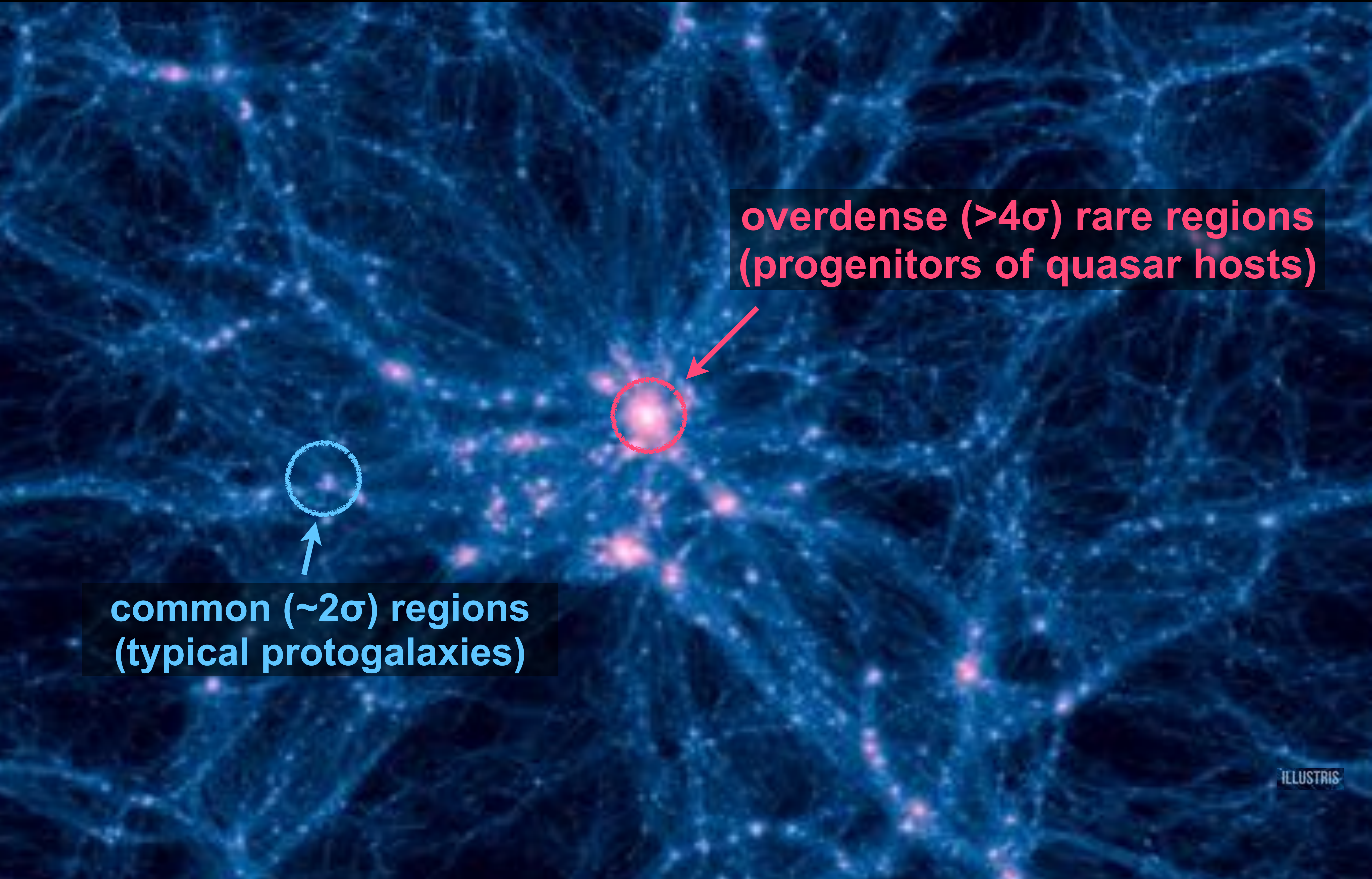
solution

$$M = M_0\ e^{t/t_{\rm Edd}} \quad \text{where} \quad t_{\rm Edd} \simeq 45\ {\rm Myr}$$

$$\sim 5 \times 10^7\ M_0 \qquad (\ t \simeq 800\ {\rm Myr}\ \text{ at z\textasciitilde 7})$$

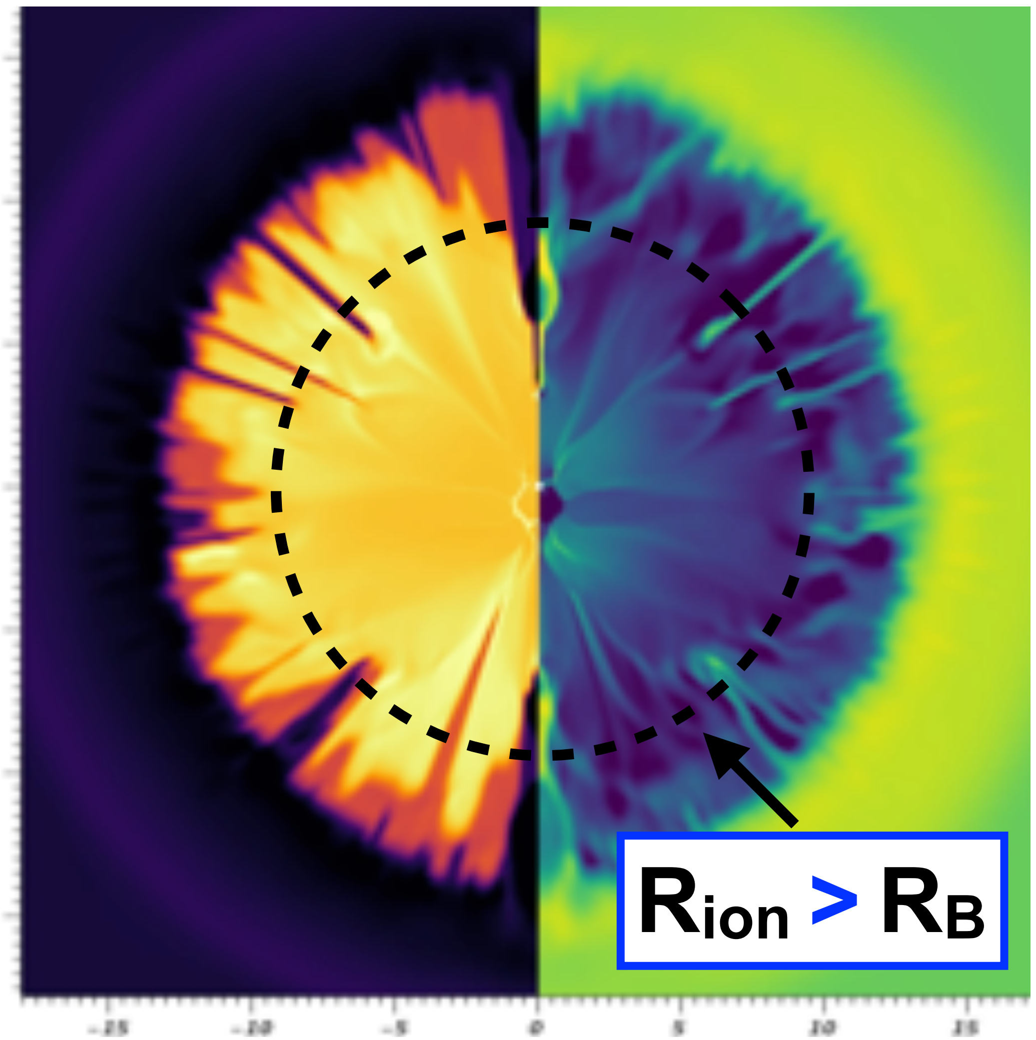
SMBHs can form from >10M_{sun} seed BHs via ‘continuous’ Eddington accretion

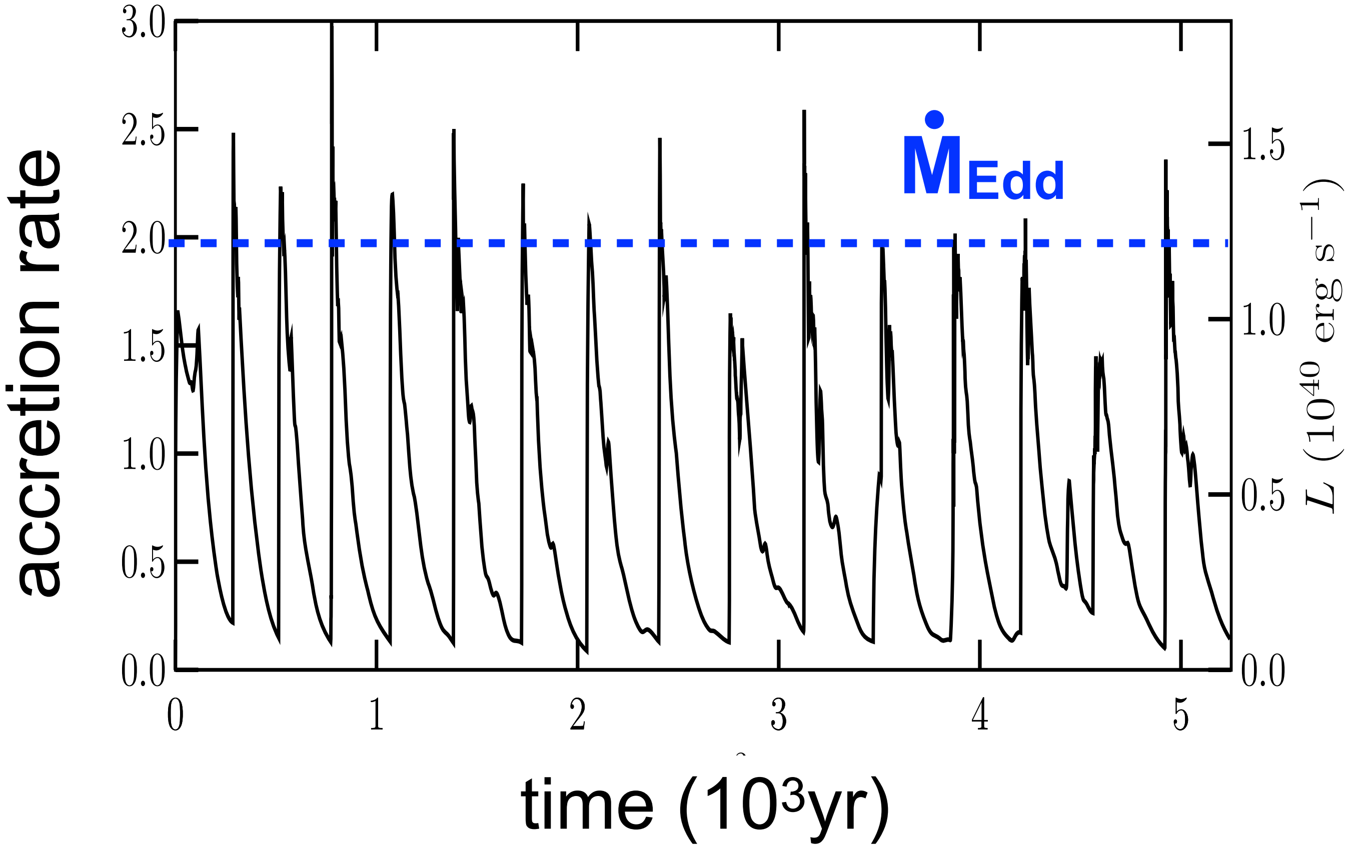
Galaxy environments



BH accretion in typical first galaxies

- Feedback regulated case ($M_{halo} = 10^7\ M_{sun}$; z=10; **2σ**)





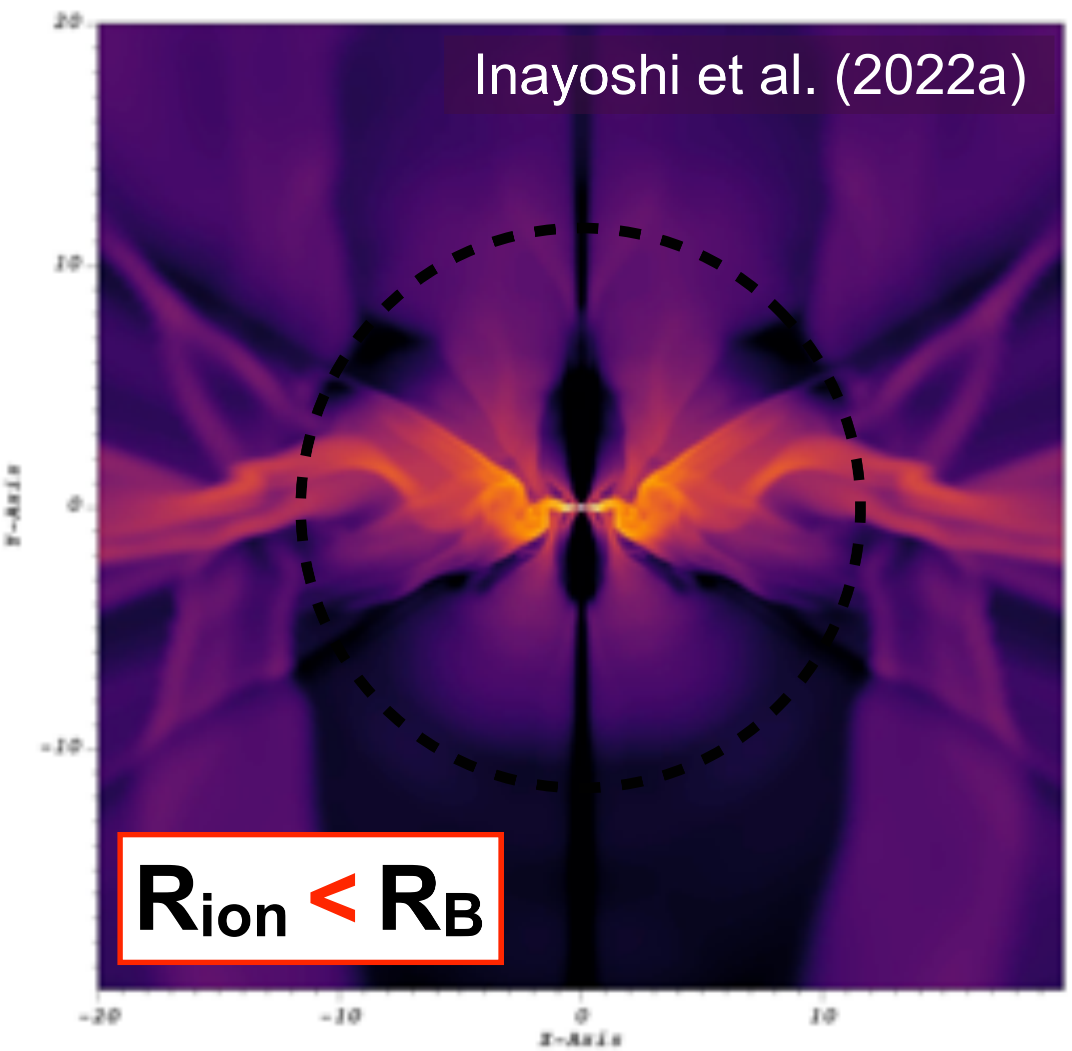
episodic accretion
(radiation heating)

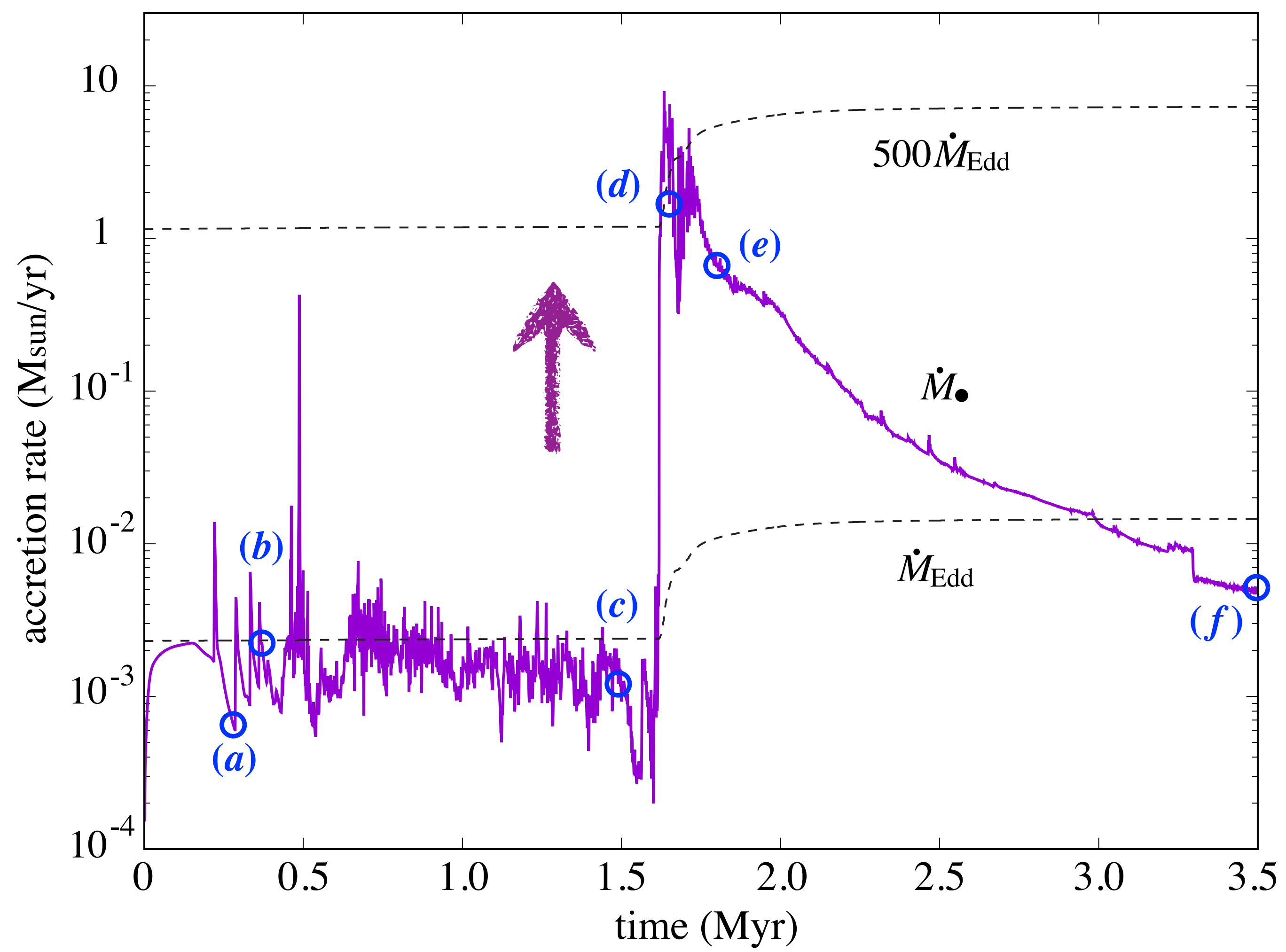
$$\langle \dot{M} \rangle \ll \dot{M}_{\rm Edd}$$

BH accretion in **massive** first galaxies

- Rapid growing case ($M_{halo} = 10^9\ M_{sun}$; z=15; **4σ**)

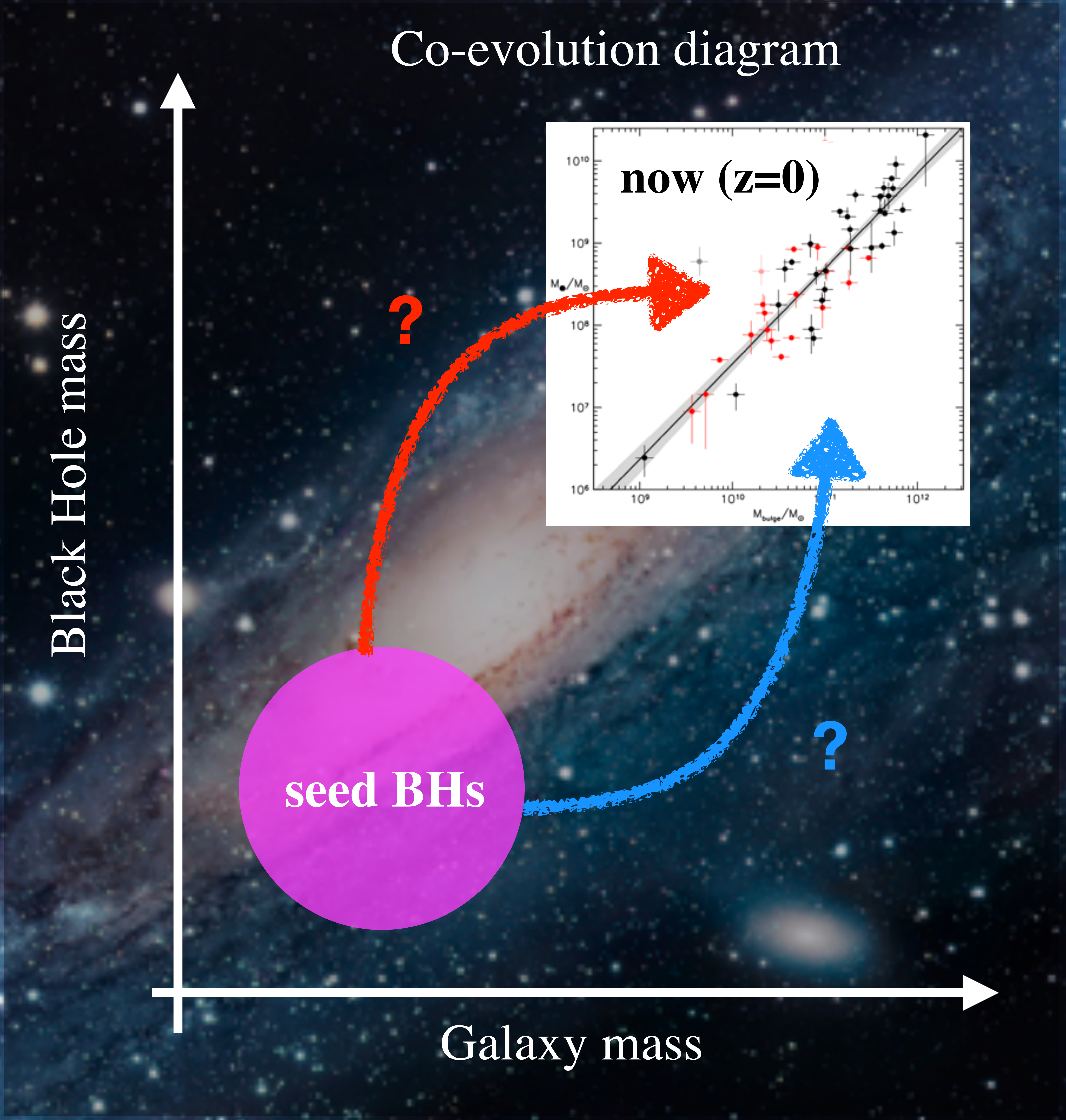
KI, Haiman & Ostriker (2016)
Takeo, KI et al. (2018,2019,2020)
Toyouchi, KI et al. (2021)



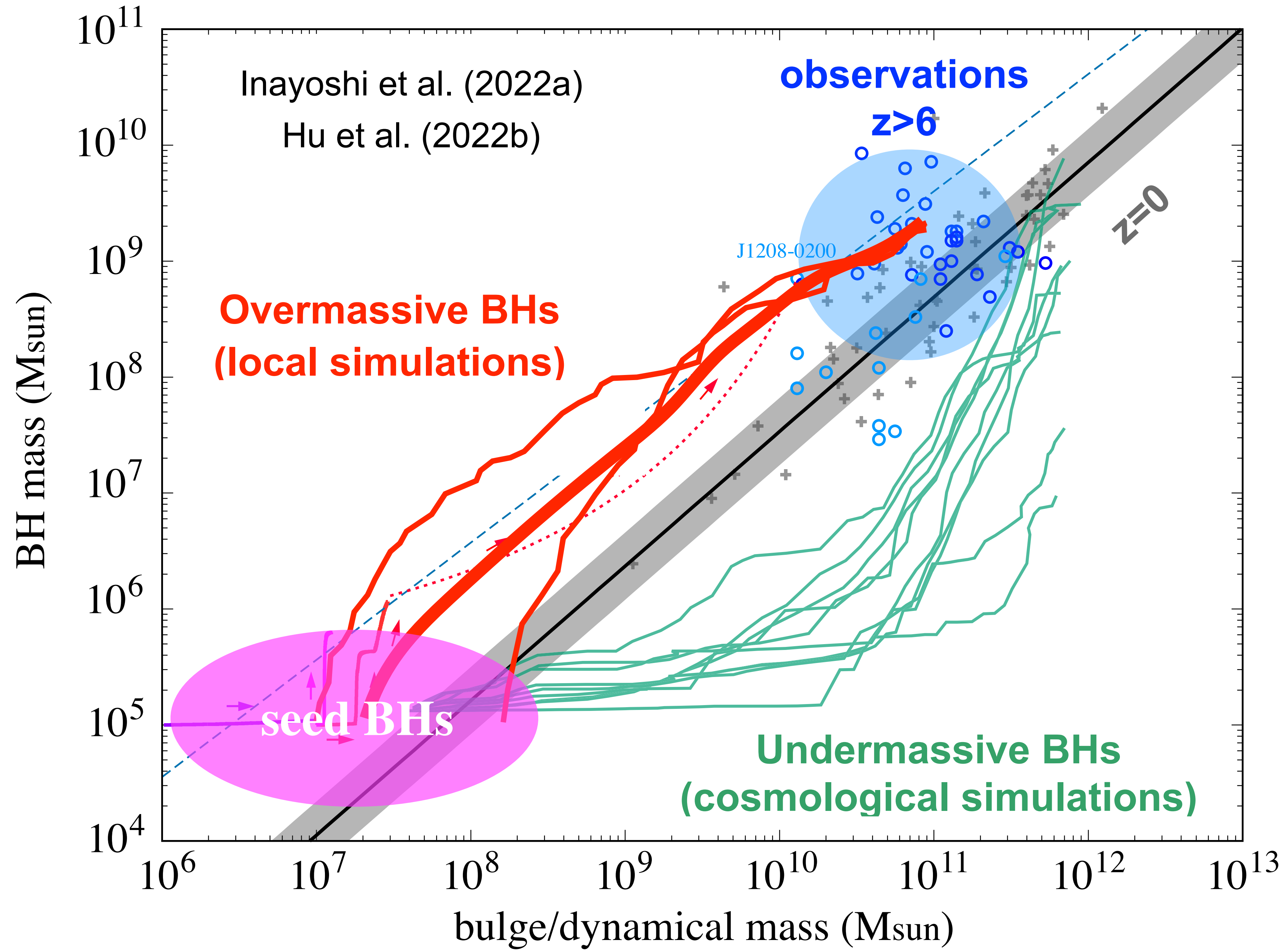


ionized bubble collapses (**R_{ion} < R_B**) → hyper-Eddington acc. $\langle \dot{M} \rangle$ **>>** $\dot{M}_{\rm Edd}$

Early BH-galaxy coevolution

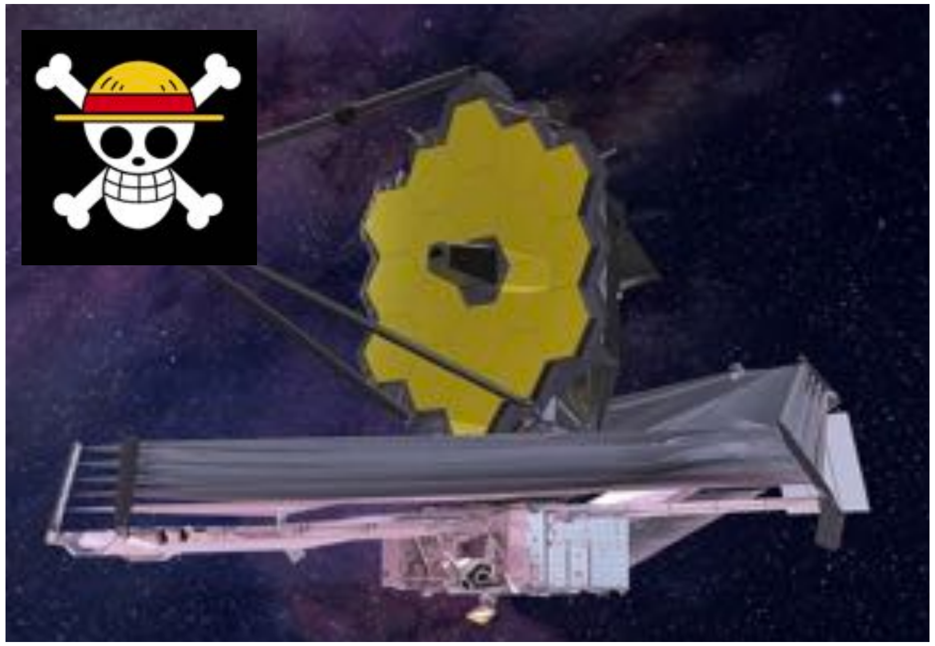


Early BH-galaxy coevolution



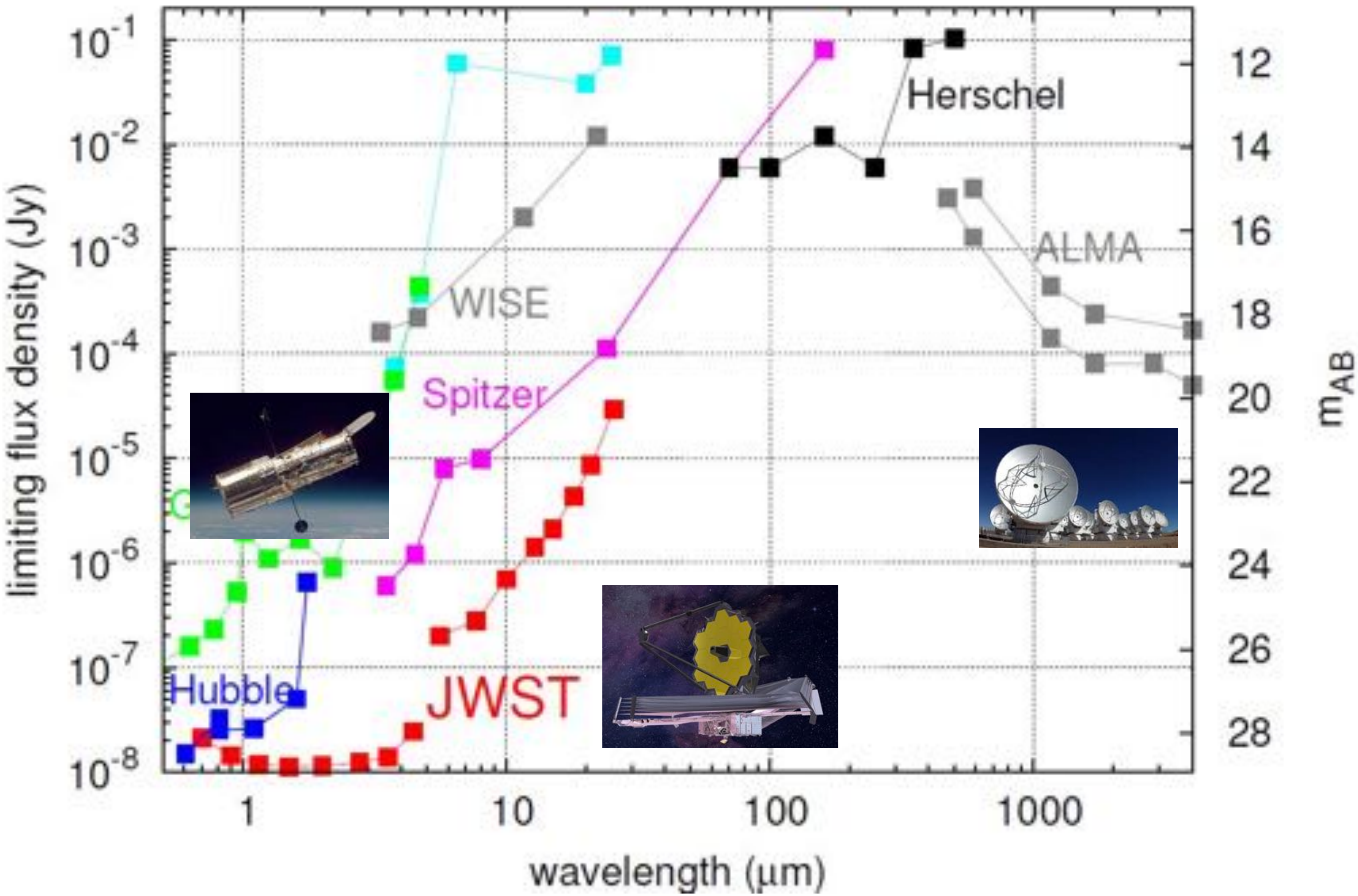
Rapid BH accretion makes them **"overmassive and bright"**

3. Excavating the First Massive BHs



James Webb Space Telescope

JWST sensitivity



UV optical infrared radio

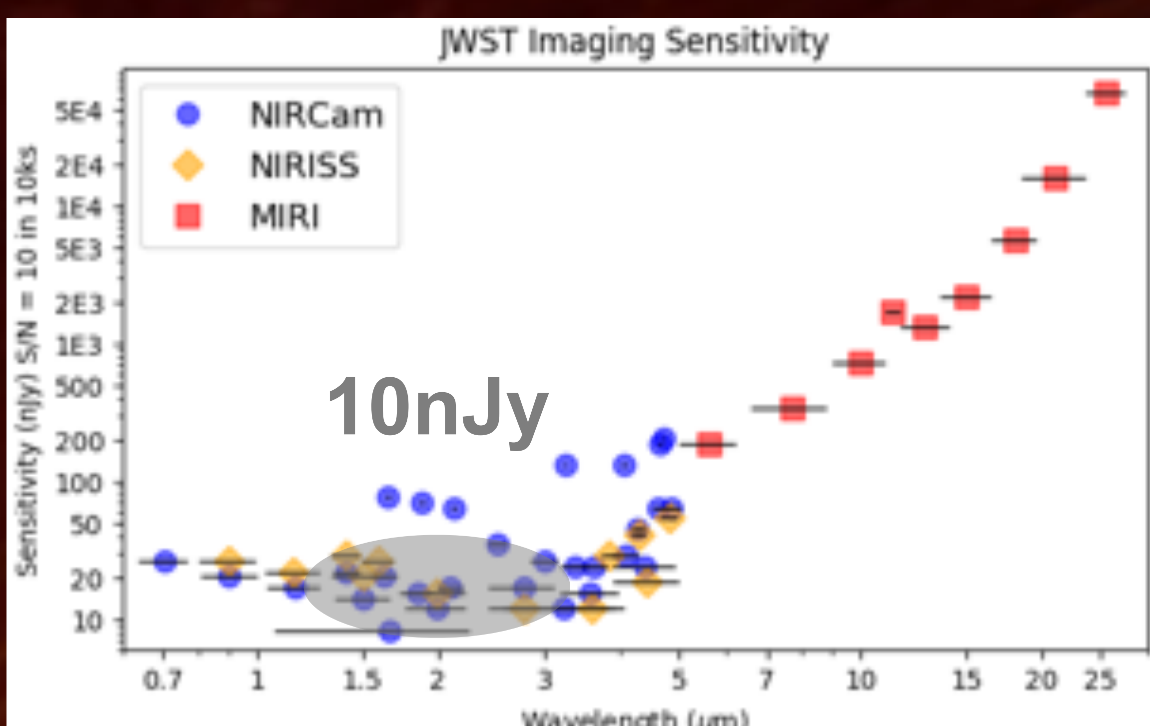
JWST for hunting seed BHs

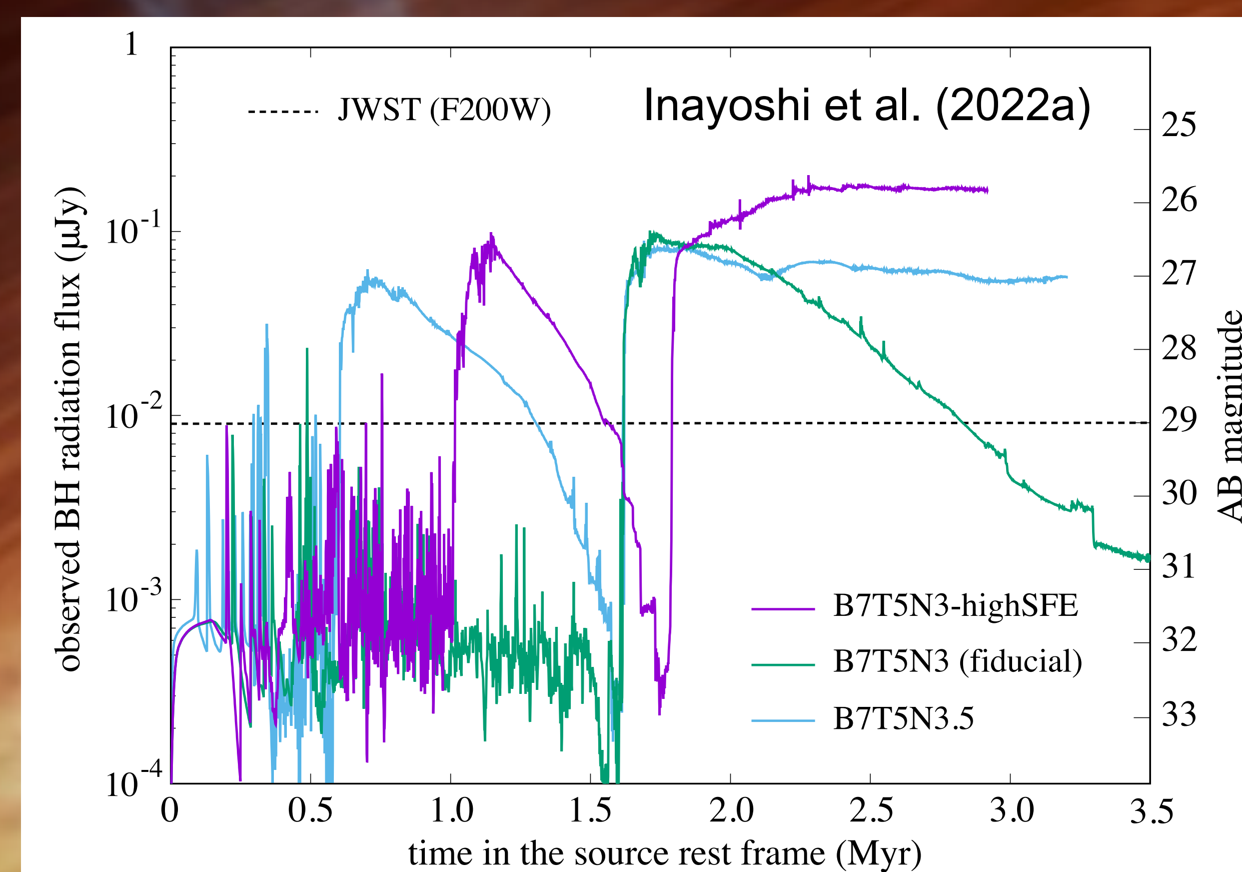
Observed wavelength **1.98μm** [(1+z)/16]

Rest-frame ~ 10eV (0.124μm)

JWST cycle 1 approved

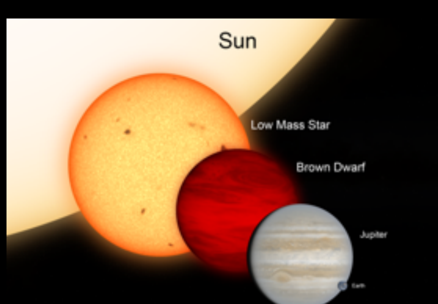
PI: M.Onoue





How to find seed BHs from images?

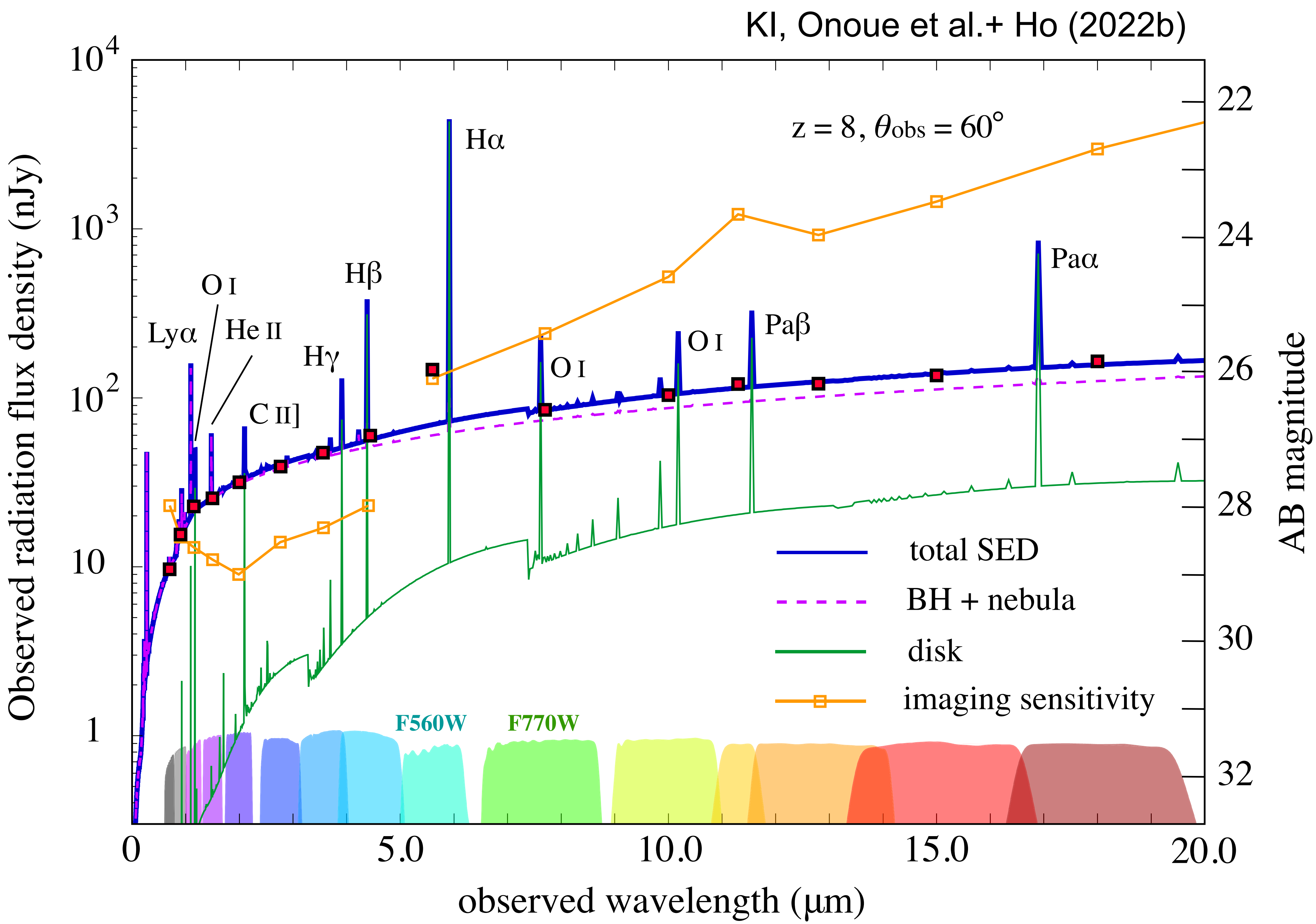
galaxies



brown dwarfs

quasars/
seed BHs?

Spectra for fast growing seed BHs



Color-cut conditions to hunt for seed BHs

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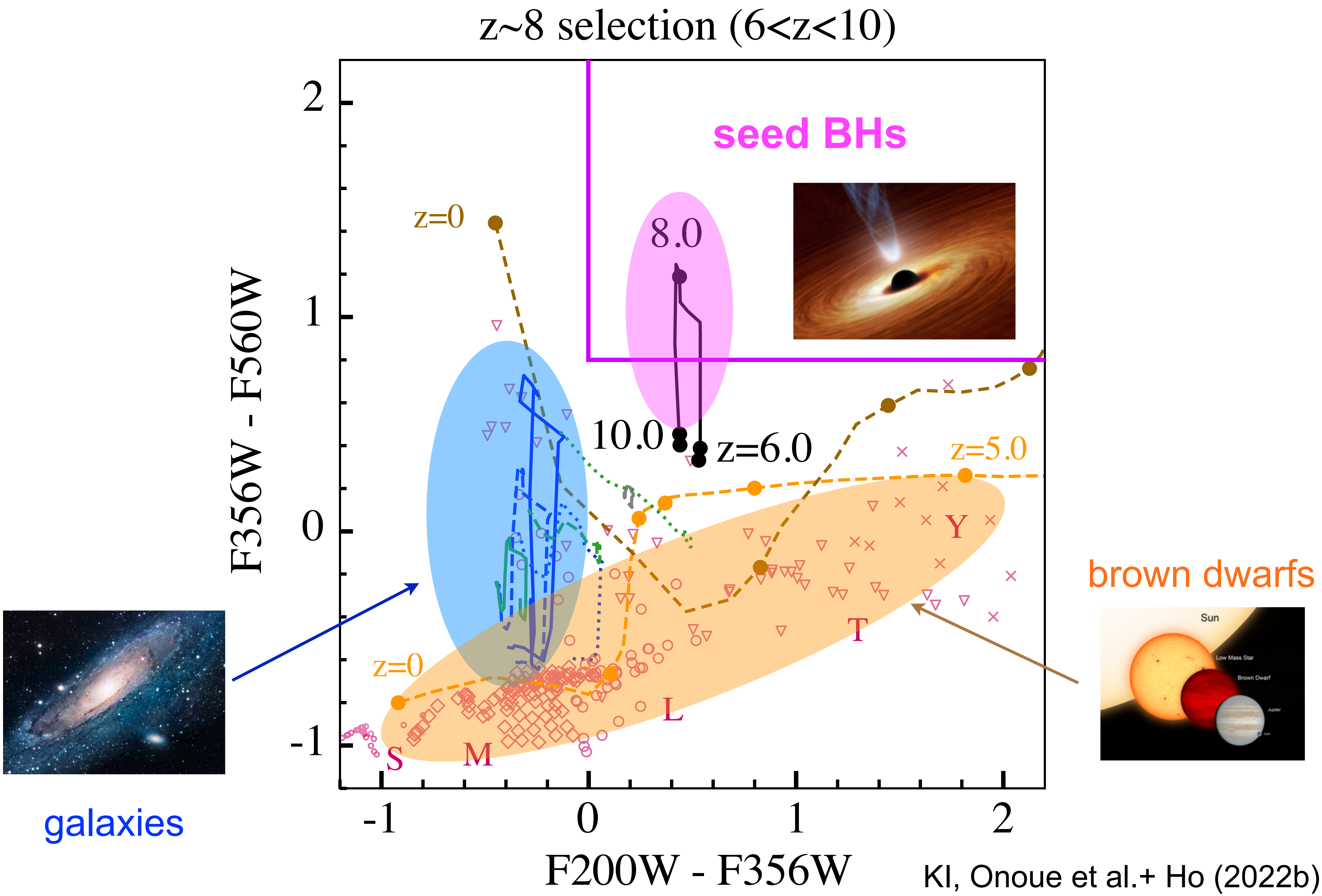
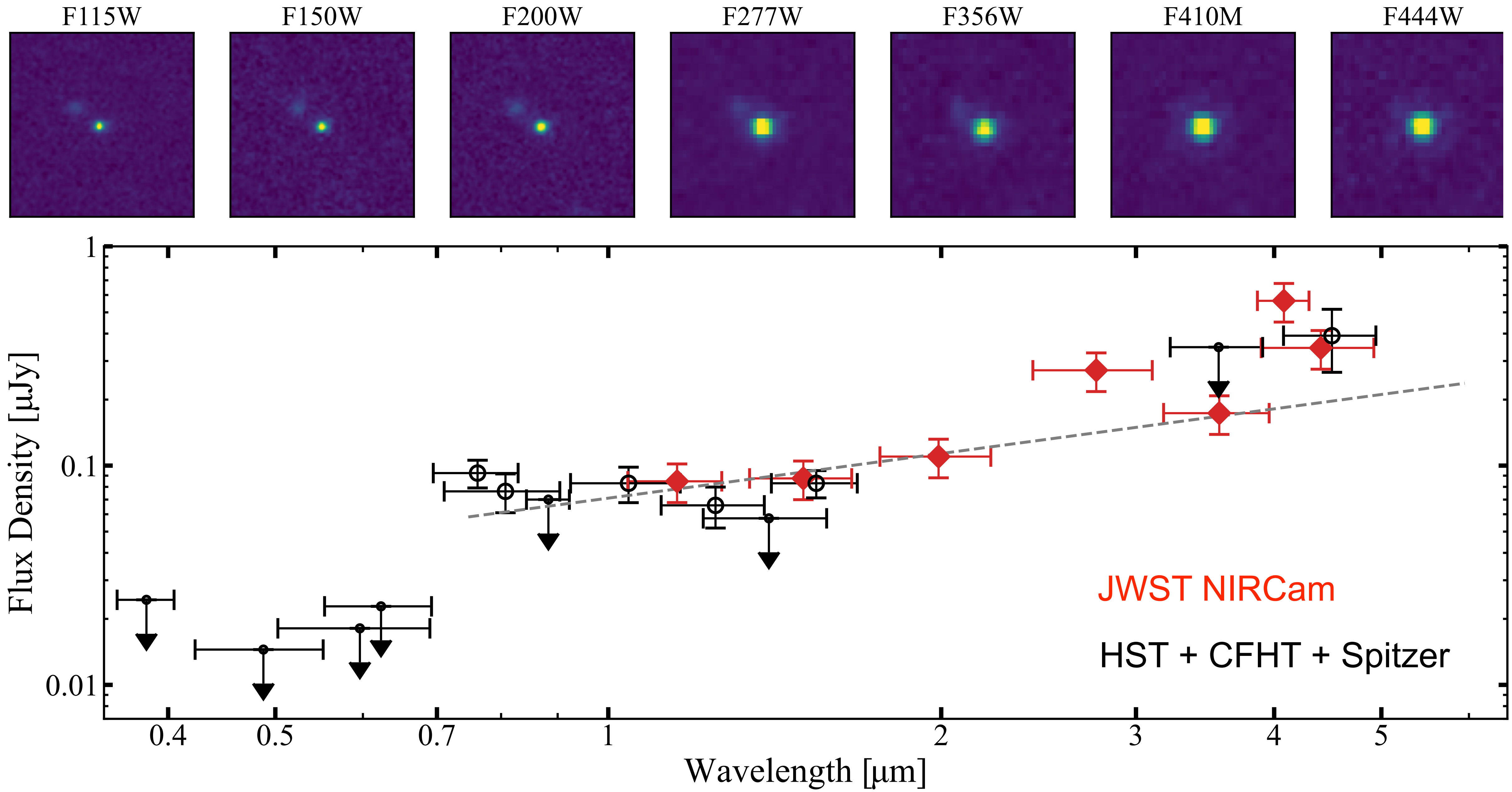


KI, Onoue et al.+ Ho (2022b)

The first AGN candidate in JWST

- CEERS-AGN-z5-1 ($L_{bol} \sim 10^{44}$ erg/s, $L_{H\beta+[OIII]} \sim L_{H\alpha} \sim 10^{43}$ erg/s)



Onoue, KI, Ding et al. (2022)
submitted yesterday!

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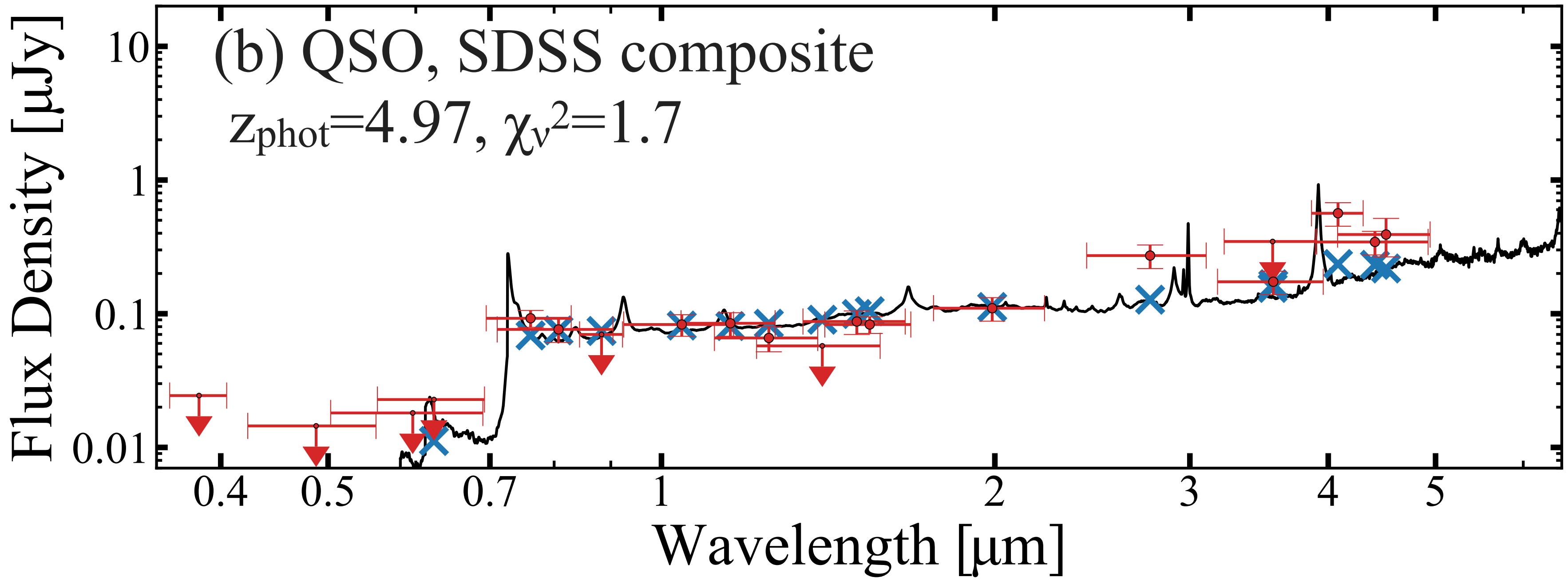
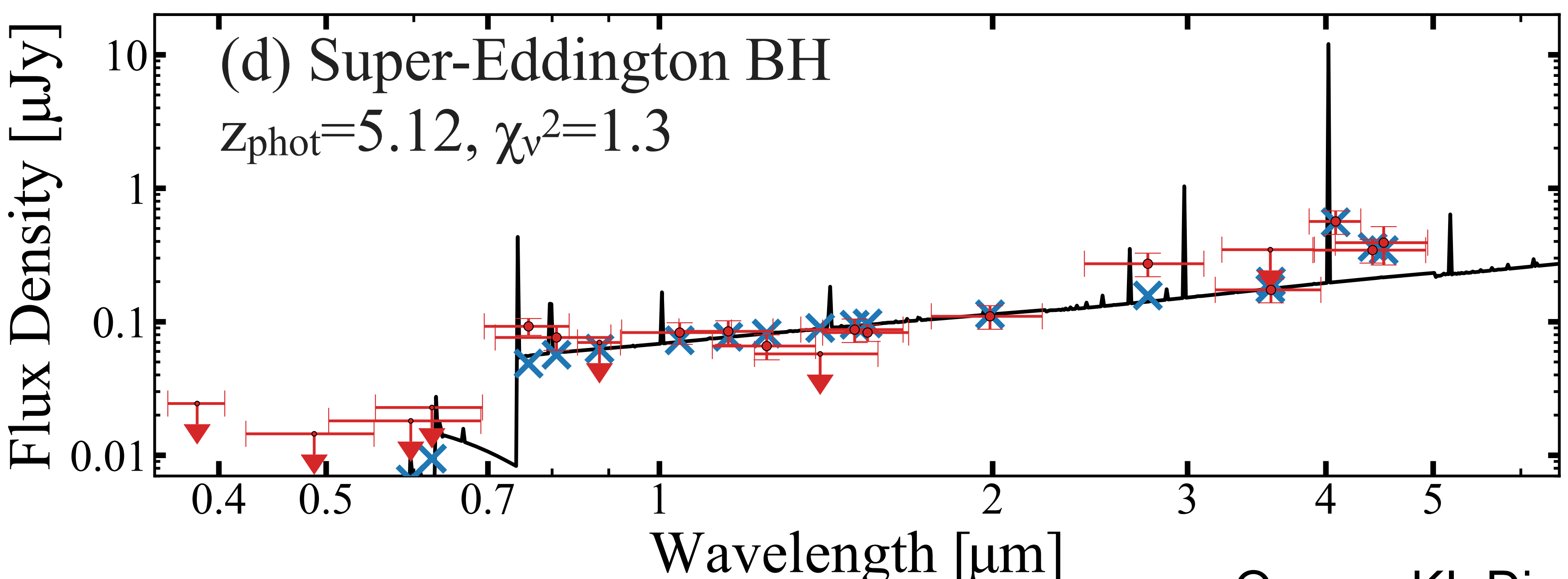
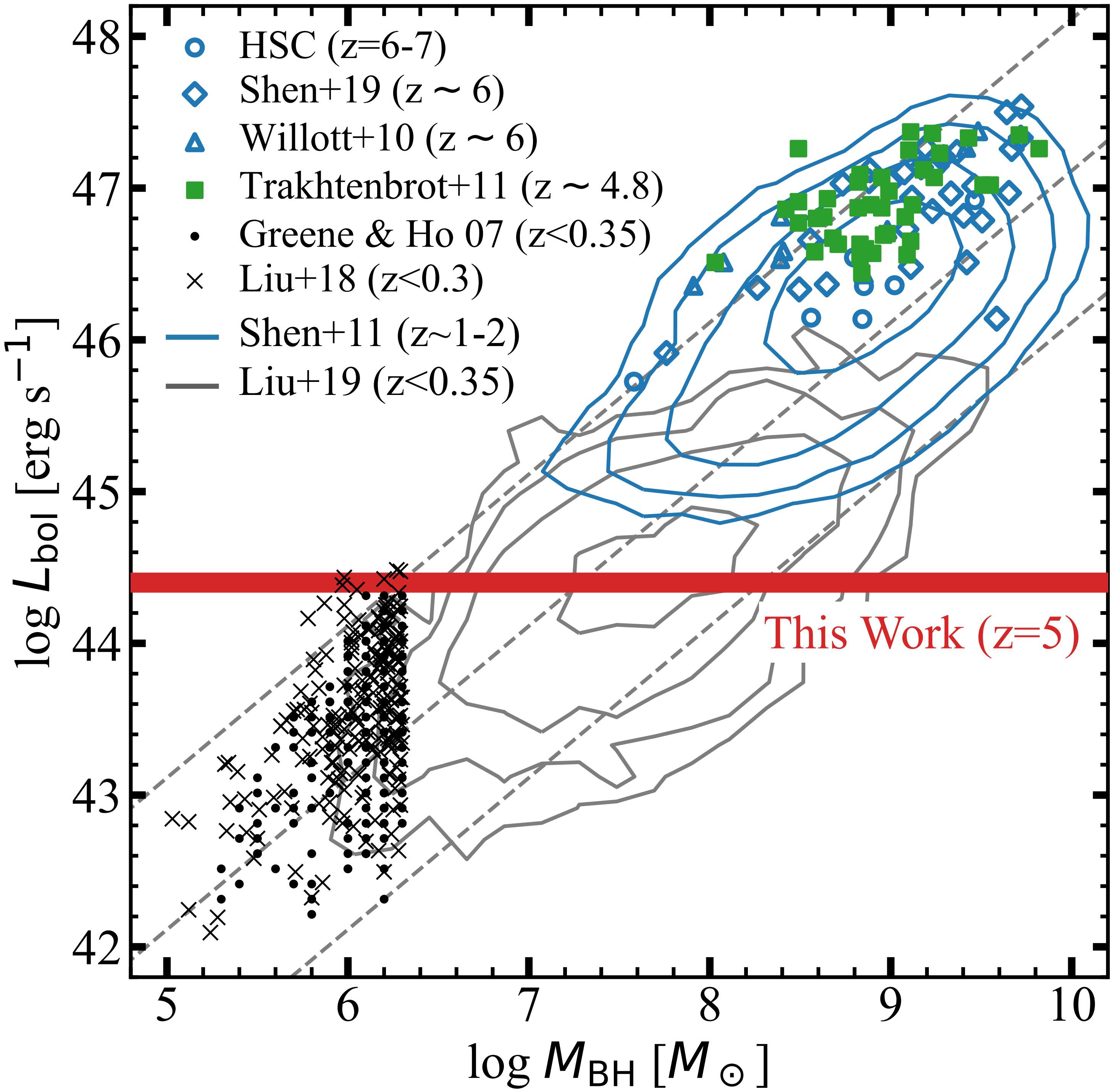




Onoue, KI, Ding et al. (2022)

The least massive BH candidates



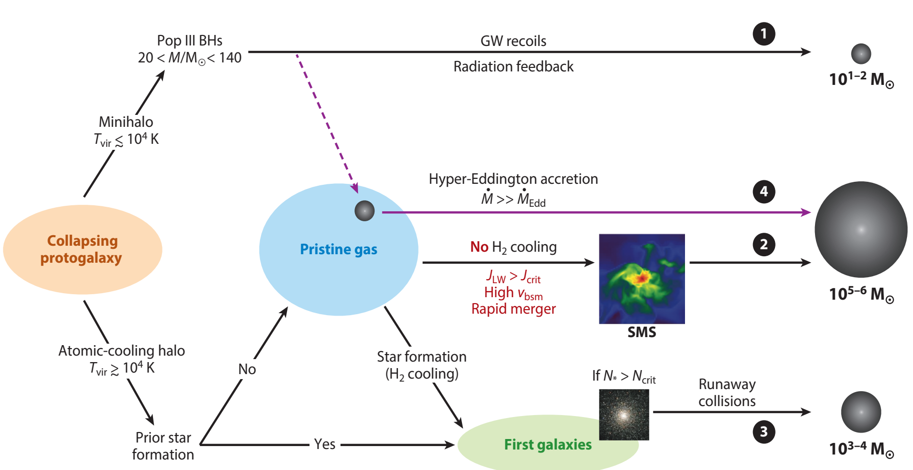
Onoue, KI, Ding et al. (2022)

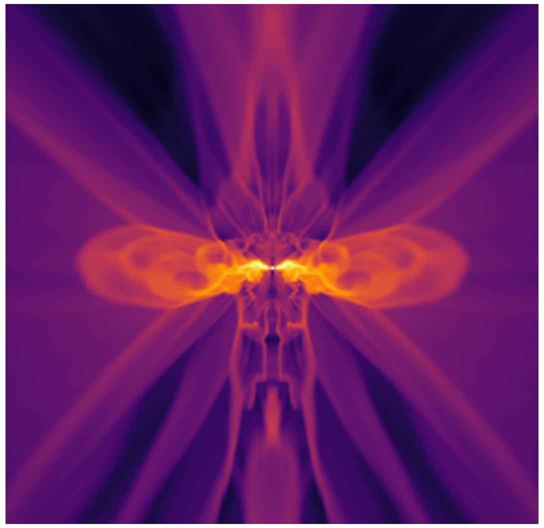
Summary

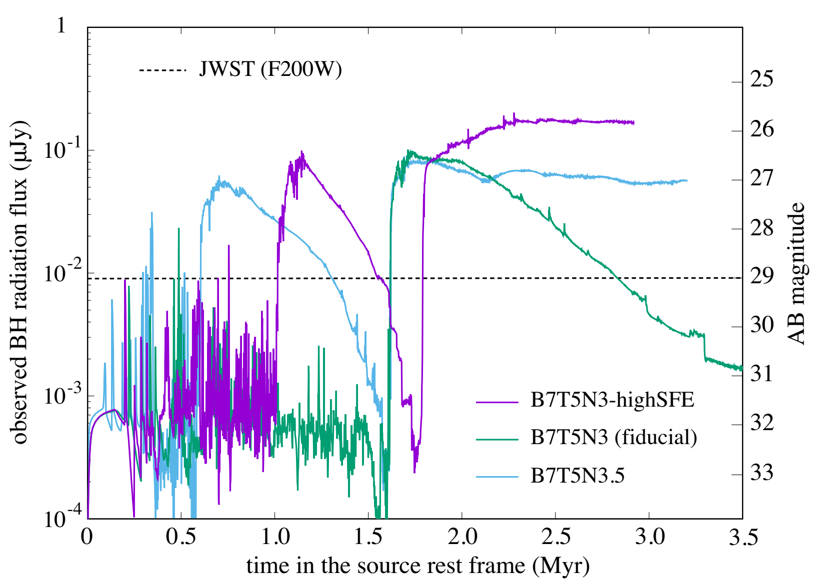
- The existence of high-z SMBHs requires their quick assembly mechanisms (massive seed formation, rapid accretion)

- Rapid accretion onto seed BHs in massive DM halos naturally explains the existence of "overmassive" BHs

- Future observations by JWST and RST will enable us to detect transient bursts (the first cry) of seed BHs







Thank you! 谢谢!